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# Joint myocardial $T_1$ and $T_2$ mapping

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## Background

Recent studies suggest that quantitative myocardial $T_1$ mapping allows assessment of focal and diffuse fibrosis in the myocardium [1]. Quantitative $T_2$ mapping has also been proposed to overcome challenges associated with $T_2$ weighted imaging [2]. These maps are traditionally acquired with different sequences, necessitating image registration to evaluate them jointly. A sequence that can jointly estimate $T_1$ and $T_2$ maps has been proposed [3], but it requires multiple relaxation cycles, which necessitates a lengthy free-breathing acquisition. In [4], an alternative joint estimation sequence was proposed based on the inversion-recovery SSFP curve. In this study, we sought to develop a saturation-recovery

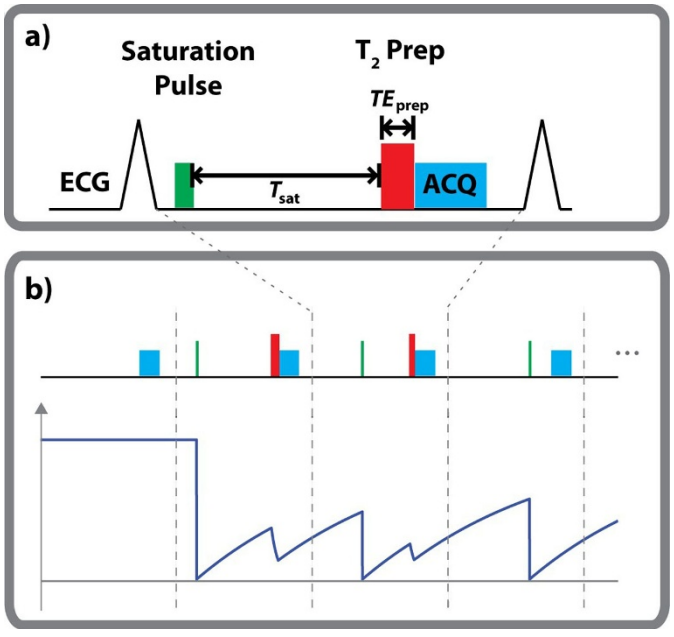


**Figure 1** a) The sequence diagram for the proposed technique. A saturation pulse is applied in every R-R interval to eliminate the magnetization history. The longitudinal magnetization then recovers for $T_{sat}$. Subsequently a $T_2$-prep with echo length $TE_{prep}$ is applied to generate the additional $T_2$ weighting, after which a single shot SSFP image is acquired. b) The mapping sequence acquires the first image with no magnetization preparation (corresponding to $T_{sat} = \infty$ and $TE_{prep} = 0$), followed by 12 images (3 are shown) acquired with different $T_{sat}$ and $TE_{prep}$ values. The major characteristics of the longitudinal magnetization signal curve are depicted under the pulse sequence diagram.

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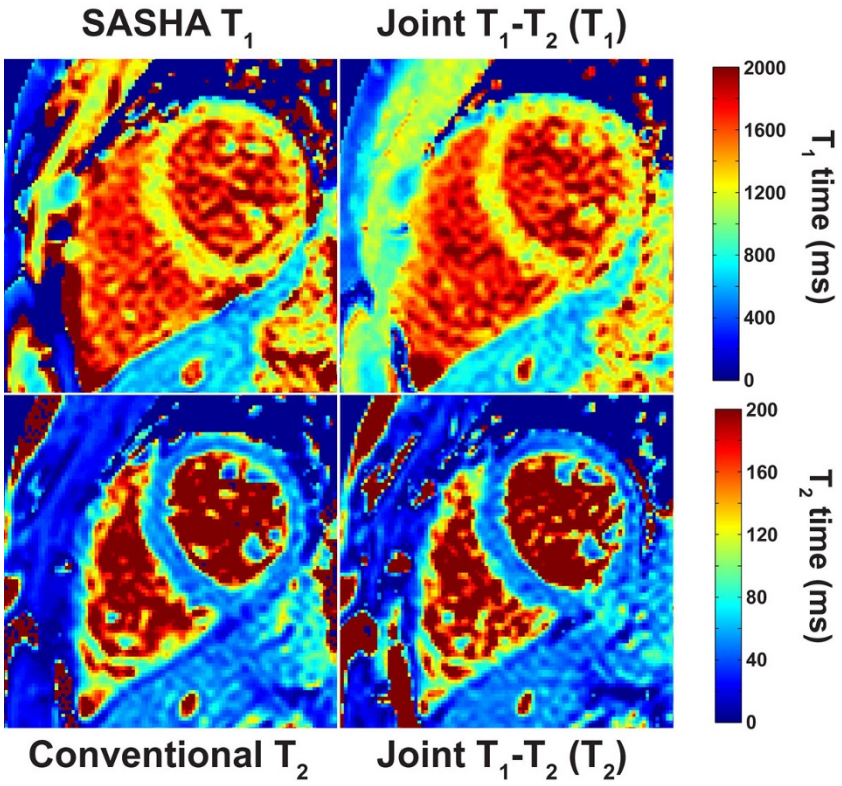


**Figure 2** $T_1$ and T maps from a healthy subject, acquired using the proposed technique, as well as SASHA $T_1$ mapping, and conventional $T_2$ mapping using 4 $T_2$prep echo times. Both the $T_1$ and $T_2$ maps generated jointly with the proposed method are similar to the individual maps with similar magnetization preparations. The myocardial $T_1$ and $T_2$ values in the septum were 1211 ± 82 ms (SASHA $T_1$), 1210 ± 92 ms (Joint $T_1$-$T_2$), 49.0 ± 5.8 ms (conventional $T_2$) and 47.3 ± 6.5 ms (Joint $T_1$-$T_2$) for each technique. The methods generated with the proposed method were acquired in the same time as each individual map, and are jointly registered by design.

based heart-rate independent sequence that can be acquired in a breath-hold and that allows for simultaneous estimation of quantitative $T_1$ and $T_2$ maps.

## Methods

The sequence diagram is depicted in Figure 1. At every heartbeat, a saturation pulse is applied to eliminate the magnetization history. The longitudinal magnetization then recovers for $T_{sat}$ based on the $T_1$ value. Subsequently a $T_2$-prep pulse [5] with echo length $TE_{prep}$ is applied to generate the additional $T_2$ weighting, after which a single shot SSFP image is acquired. The process is repeated for 13 heartbeats with various ($T_{sat}^k$, $TE_{prep}^k$) corresponding to heartbeat *k*, to sample different $T_1$-$T_2$ weighted images. The first heartbeat is acquired with no magnetization preparation.

The $T_1$ and $T_2$ maps were estimated jointly by voxel-wise least squares fitting to a 4-parameter signal model, $A\ (1- \exp(-T_{sat}^k/T_1))\ \exp(-TE_{prep}^k/T_2) + B$. Phantom imaging of 14 vials with different $T_1/T_2$ values were performed and compared to inversion-recovery and CPMG spin-echo references, respectively. Breath-held in-vivo imaging was performed on 5 healthy adult subjects, and the maps were compared to SASHA $T_1$ maps [6] and to $T_2$ maps [7].

## Results

Phantom imaging resulted in $T_1$ and $T_2$ values not significantly different than the references ($P$ = 0.481 and 0.479 respectively). Example in-vivo $T_1$ and $T_2$ maps are depicted in Figure 2, comparing various techniques. The $T_1$ and $T_2$ values were in good agreement (1211 ± 82 ms vs. 1210 ± 92 ms for $T_1$; 49.0 ± 5.8 ms and 47.3 ± 6.5 ms for $T_2$).

## Conclusions

The proposed sequence allows for the simultaneous estimation of accurate and jointly registered quantitative $T_1$ and $T_2$ maps with similar accuracy and precision to saturation-based $T_1$ mapping and to $T_2$ mapping of same duration.

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